526 Rec'd PCT/PTO 04 OCT 2000

U.S. DEPARTMENT OF COMMERCE PATENT & TRADEMARK OFFICE

| B/O Form PTO-1390 **Transmittal Letter to the United States Designated/Elected Office (DO/EO/US) Concerning a Filing Under *35 USC 371*** | | *Attorney's Docket Number* REF/KIM/174 |
|---|---|---|
| | | *U S Application Number (if known)* 09/623516 |
| *International Application Number* PCT/KR99/00174 | *International Filing Date* 13 April 1999 | *Priority Date Claimed* 13 April 1998 |
| *Title of Invention* METHOD AND APPARATUS FOR MEASURING SIMILARITY USING MATCHING PIXEL COUNT | | |
| *Applicant(s) for DO/EO/US* Hyoung Gon KIM et al. | | |

**Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items under *35 USC 371*:**

1. ☒ This is a **FIRST** submission of items concerning a filing under *35 USC 371*.

2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under *35 USC 371*.

3. ☒ This express request to begin national examination procedures *(35 USC 371(f))* at any time rather than delay examination until the expiration of the applicable time limit set in *35 USC 371(b)* and PCT Articles 22 and 39(1).

4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.

5. ☒ A copy of the International Application as filed *35 USC 371(c)(2)*.
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).

6. ☐ A translation of the International Application into English *(35 USC 371(c)(2))*.

7. ☒ Amendments to the claims of the International Application under PCT Article 19 *(35 USC 371(c)(3))*
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.

8. ☐ A translation of the amendments to the claims under PCT Article 19 *(35 USC 371(c)(3))*.

9. ☒ An oath or declaration of the inventor(s) *(35 USC 371(c)(4))*. ( ☒ Executed ☐ Unexecuted)

10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 *(35 USC 371(c)(5))*.

***Items 11 to 16 below concern other document(s) or information included:***

11. ☒ An Information Disclosure Statement under *37 CFR 1.97* and *1.98*.

12. ☒ An assignment document for recording. A separate cover sheet in compliance with *37 CFR 3.28* and *3.31* is included.

13. ☐ A **FIRST** preliminary amendment.
    ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.

14. ☐ A substitute specification.

15. ☐ A change of power of attorney and/or address letter.

16. ☐ Other items or information:

526 Rec'd PCT/PTO 04 OCT 2000

| Application Number (if Known) | International Application Number | Attorney's Docket Number | |
|---|---|---|---|
| 09/ 623516 | PCT/KR99/00174 | REF/KIM/174 | |
| | | **Calculations** | **PTO USE ONLY** |
| 17. The following fees are submitted:<br>**Basic National Fee** ***(37 CFR 1.492(a)(1)-(5)):***<br>☐ Search report has been prepared by the EPO or JPO .................... $860.00<br>☐ International Preliminary Examination Fee paid to USPTO *(37 CFR 1.482)* ..... $690.00<br>☐ No International Preliminary Examination Fee paid to USPTO *(37 CFR 1.482)* but International Search Fee paid to USPTO *(37 CFR 1.445(a)(2))* ......... $710.00<br>☒ Neither International Preliminary Examination Fee *(37 CFR 1.482)* nor International Search Fee *(37 CFR 1.445(a)(2))* paid to USPTO ............ $1000.00<br>☐ International Preliminary Examination Fee paid to USPTO *(37 CFR 1.482)* and all claims satisfied provisions of PCT Article 33(1)-(4) ............... $100.00 | | $1,000.00 | |
| **ENTER APPROPRIATE BASIC FEE AMOUNT** | | **$ 1,000.00** | |
| Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date *(37 CFR 1.492(e))*. | | | |

| CLAIMS | NUMBER FILED | | NUMBER EXTRA | RATE | | |
|---|---|---|---|---|---|---|
| Total Claims | 13 | -20 = | 0 | × $18.00 | $ 0.00 | |
| Independent Claims | 2 | -3 = | 0 | × $80.00 | $ 0.00 | |
| Multiple Dependent Claims (if applicable) | | | | + $270.00 | | |

| | | |
|---|---|---|
| **TOTAL OF ABOVE CALCULATIONS** | **$ 0.00** | |
| Reduction by ½ for filing by small entity, if applicable. Verified Small Entity Statements must also be filed (Note *37 CFR 1.9, 1.27, 1.28*) | $ 500.00 | |
| **SUBTOTAL** | **$ 500.00** | |
| Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date *(37 CFR 1.492(f))*. | | |
| **TOTAL NATIONAL FEE** | | |
| Fee for recording the enclosed assignment *(37 CFR 1.21(h))*. The assignment must be accompanied by an appropriate cover sheet *(37 CFR 3.28, 3.31)*. **$40.00** per property. | $ 40.00 | |
| **TOTAL FEES ENCLOSED** | **$ 540.00** | |
| Amount to be: | Refunded: | |
| | Charged: | |

a. ☒ A check in the amount of **$540.00** to cover the fees is enclosed.
b. ☐ Please charge my **Deposit Account Number 02-0200** in the amount of $ ________ to cover the above fees. A duplicate copy of this sheet is enclosed.
c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to **Deposit Account Number 02-0200**. A duplicate copy of this sheet is enclosed.

Note: Where an appropriate time limit under *37 CFR 1.494* or *1.495* has not been met, a petition to revive *(37 CFR 1.137(a) or (b))* must be filed and granted to restore the application to pending status.

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DATE: October 4, 2000

*Respectfully submitted,*

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(01OCT00)

*NonProfit Organization*

# VERIFIED STATEMENT (DECLARATION) BY A NONPROFIT ORGANIZATION CLAIMING SMALL ENTITY STATUS UNDER *37 CFR 1.9(F)* AND *1.27(d)*

Applicant or Patentee: KIM, HYOUNG GON/ CHU, SUNG MIN AHN, SANG CHUL/ KIM, NAM KYU
Docket #:
Serial or Patent Number:
Group Art Unit:
Filed or Issued:
Examiner:
Title: METHOD AND APPARATUS FOR MEASURING SIMILARITY USING MATCHING PIXEL COUNT

I hereby declare that I am an official empowered to act on behalf of the nonprofit organization identified below:
Name of Organization: KOREA INSTITUTE OF SCIENCE AND TECHNOLOGY
Address: #39-1, HAWOLOGOK-DONG, SUNBUK-GU, SEOUL, 136-791, REPUBLIC OF KOREA

*Type of Organization*

- ☒ University or other institution of higher education.
- ☐ Tax exempt under Internal Revenue Service code (*26 USC 501(a) and 501(c)(3)*).
- ☐ Nonprofit scientific or educational under statute of state of the United States of America. Name of State: Statute:
- ☐ Would qualify as tax exempt under Internal Revenue Service code *(26 USC 501(a) and 501(c)(3))* if located in the United States of America.
- ☐ Would qualify as nonprofit scientific or educational under statute of state of the United States of America if located in the United States of America. Name of State: Statute:

I hereby declare that the nonprofit organization identified above qualifies as a nonprofit organization as defined in *37 CFR 1.9(e)* for purposes of paying reduced fees under *section 41(a) or (b) of Title 35, United States Code* with regard to the matter described in:

- ☐ The specification filed herewith, with the title as listed above.
- ☐ The patent application identified above.
- ☒ The PCT international patent application identified above.
- ☐ The patent number identified above.

I hereby declare that rights under contract or law have been conveyed to and remain with the nonprofit organization with regard to the above identified invention.

If the rights held by the above identified nonprofit organization concern are not exclusive, each individual, concern or organization having rights to the invention must file separate verified statements averring to their status as small entities and that no rights to the invention are held by any person, other than the inventor, who could not qualify as an independent inventor under *37 CFR 1.9(c)* if that person made the invention, or by any concern which would not qualify as a small business concern under *37 CFR 1.9(d)* or a nonprofit organization under *37 CFR 1.9(e)*. Each person, concern or organization having any rights in the invention is listed below:

- ☒ No such person, concern or organization.
- ☐ Each such person, concern or organization as listed below:

| | |
|---|---|
| *FULL NAME:* | ☐ Individual<br>☐ Small Business Concern<br>☐ NonProfit Organization |
| *ADDRESS:* | |

| | |
|---|---|
| *FULL NAME:* | ☐ Individual<br>☐ Small Business Concern<br>☐ NonProfit Organization |
| *ADDRESS:* | |

☐ See attached sheet for additional person(s) concern(s) or organization(s).

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate *(37 CFR 1.28(b))*.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine, or imprisonment, or both, under *section 1001 of Title 18 of the United States Code*, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which the verified statement is directed.

| *Name and Title in Organization* | *Date* |
|---|---|
| KOREA INSTITUTE OF SCIENCE AND TECHNOLOGY | SEPTEMBER 30, 2000 |
| *Address* | *Signature* |
| 39-1, HAWOLOGOK-DONG, SUNBUK-GU, SEOUL, 136-791, REPUBLIC OF KOREA | 김 기 현 |

PTO/PCT Rec'd 04 OCT 2000 09/623516



# METHOD AND APPARATUS FOR MEASURING SIMILARITY USING MATCHING PIXEL COUNT

## Technical Field:

The present invention relates to digital image processing and, more particularly, to a method and apparatus for measuring similarity between pixels in two different images.

## Background Art:

Stereo disparity estimation is one of the most active research areas in the field of three-dimensional or stereo vision. Stereo disparity is the spatial offset or displacement between two matching pixels, where one pixel is in a reference image, the other pixel is in a search image, and both pixels correspond to the same point in physical space. The reference and search images are the images viewed by the left and right eyes, respectively.

In order to determine the pixel in the search image which matches a given pixel in the reference image, the coordinates of the pixels in the two images must first be established. A similarity measure is then computed between pixels in a window of predetermined size centered at the given pixel in the reference image (*i.e.*, the reference pixel) and pixels that are candidates to match the reference pixel in a window of the same size centered at each candidate pixel in the search image. The pixel in the search image that yields the greatest value of the similarity measure is considered to be the pixel that matches the reference pixel.

A disparity map for the reference image is obtained by computing the similarity measure between a reference pixel and each candidate matching pixel in a search range for every pixel in the reference image. Generation of the disparity map is greatly simplified by imposition of the "epipolar constraint"

on the candidate matching pixels, whereby the candidate matching pixels are limited to those which lie on the same horizontal line as the reference pixel.

Figure 1 illustrates matching subject to the epipolar constraint. To determine the pixel in the search image that most closely matches the starred reference pixel, the similarity measure is computed for a window centered at the reference pixel and a window in the search image centered at a candidate matching pixel as the window in the search image is moved along a horizontal line within a search range. The candidate search pixel that yields the greatest value of the similarity measure is considered to be the pixel that matches the reference pixel. The spatial displacement between the matching pixel from the reference pixel is the stereo disparity for the reference pixel.

Similarity measures typically used to determine matching pixels include the <u>s</u>um of <u>s</u>quared <u>d</u>ifferences (SSD), the <u>s</u>um of <u>a</u>bsolute <u>d</u>ifferences (SAD), and the <u>n</u>ormalized <u>c</u>ross <u>c</u>orrelation (NCC). For each of these similarity measures, the contribution of a given search pixel to the disparity map depends on the light intensity at the given search pixel. The disparity boundary between a region within which there are large variations in light intensity therefore tends to extend into any adjacent region within which there are small variations in light intensity. This phenomenon, known as "boundary overreach", generates misleading disparity values near the boundary of an object.

## Disclosure of Invention:

An object of the present invention is accordingly to suppress boundary overreach in the estimation of stereo disparity by providing a similarity measure based on a matching pixel count ("MPC"), the number of search pixels having similar intensity values, rather than on the light intensity at each

of the search pixels. Another object of the present invention is to provide an apparatus for estimating stereo disparity that efficiently implements the above method in real time.

One embodiment of the present invention is a method for determining the stereo disparity between a reference image and a search image for a reference pixel in the reference image, the method comprising the steps of:

(a) calculating a similarity measure between a reference window in the reference image, which reference window includes a set of pixels centered at the reference pixel, and each of a plurality of search windows in the search image, each of which search windows has the same shape as the reference window and is displaced from the reference window within a predetermined search range, wherein a matching pixel count, the number of pixels in the reference window at which the light intensity is similar to the light intensity at the corresponding pixels in the search window, is used as the similarity measure between the reference window and the search window; and

(b) determining a displacement between the reference window and a search window which yields the greatest value of the similarity measure as the stereo disparity for the reference pixel.

Another embodiment of the present invention is an apparatus for determining the stereo disparity between a reference image and a search image for a reference pixel in the reference image, the apparatus comprising:

(a) first means for calculating a similarity measure between a reference window in the reference image, which reference window includes a set of pixels centered at the reference pixel, and each of a plurality of search windows in the search image, each of which search windows has the same shape as the reference window and is displaced from the reference window within a predetermined search range, wherein a matching pixel count, which is the number of pixels in the

reference window which are similar in intensity to corresponding pixels in a search window, is used as the similarity measure between the reference window and the search window; and

(b) second means for determining a displacement between the reference window and a search window which yields a largest value of the similarity measure as the stereo disparity for the reference pixel,

wherein R(x,y) denotes the reference pixel, the reference window includes Wx*Wy pixels centered at R(x,y), Wx and Wy being predetermined numbers, each of the search windows includes Wx*Wy pixels centered at L(x+d, y) which is a pixel in the search image, d ranging from 0 to a predetermined number Sr, and

the first means includes:

(a1) a P-unit for calculating P(x,y,d), where:

$P(x,y,d) = 1$, if $abs(B_R(x,y)-B_L(x+d,y)) \le Th$ and

$P(x,y,d) = 0$, otherwise,

where $B_R(x,y)$ and $B_L(x+d,y)$ denote the intensity values at R(x,y) and L(x+d,y), respectively, and Th is a predetermined threshold value;

(a2) a P-buffer for storing P(x,y,d) values calculated by the P-unit; and

(a3) third means for determining MPC(x,y,d) values for d=0 to Sr as follows:

$$MPC(x,y,d) = \sum_{w} P(x,y,d)$$

where w denotes the reference window and a search window; and

the second means includes means for selecting a d value which yields a largest MPC(x,y,d) value as the stereo disparity for R(x,y).

<u>Brief Description of Drawings:</u>

Figure 1 illustrates matching subject to an epipolar constraint.

Figure 2 illustrates the comparative performance of the SAD and MPC similarity measures.

Figures 3A and 3B illustrate redundant operations involved in determining the MPC similarity measure.

Figures 4A and 4B illustrate a method of determining the MPC similarity measure from which redundant operations have been eliminated.

Figure 5 is a flow chart for determining the MPC similarity measure in accordance with an embodiment of the present invention.

Figure 6 shows an apparatus for determining a disparity map D(x,y) in accordance with an embodiment of the present invention.

Figure 7A illustrates the internal structure of the P-buffer of the apparatus shown in Figure 6.

Figure 7B illustrates the internal structure of the V-buffer of the apparatus shown in Figure 6.

Figure 8A illustrates the internal structure of the P-unit of the apparatus shown in Figure 6

Figure 8B is a circuit diagram of the D_P unit of the P-unit illustrated in Figure 8A.

Figure 9 illustrates the internal structure of one of the MPC-units of the apparatus shown in Figure 6.

Figure 10 is a logic diagram of the MPC-unit whose internal structure is illustrated in Figure 9.

Figure 11 illustrates the internal structure of the Max_MPC selector of the apparatus shown in Fig\ure 6.

Best Mode for Carrying out the Invention:

In the method described and claimed in the present application, a matching pixel count ("MPC") is used as a measure of the similarity between a reference window in a reference image and each of a plurality of search windows in a search image. The contribution of a given matching pixel in

the search image to the similarity measure is taken to be the same irrespective of the intensity at the given matching pixel in order to ensure an accurate result near the boundary of the image. MPC is computed by counting the number of pixels in a window in one image whose corresponding pixels in another image have similar intensity values.

When the reference and search windows satisfy the epipolar constraint, MPC(x, y, d) denotes the similarity between a reference window centered at R(x, y) and a search window centered at L(x+d, y), where R(x, y) is a pixel in the reference image located at (x, y) and L(x+d, y) is a pixel in the search image located at (x+d, y). MPC(x, y, d) is defined by:

$$MPC(x,y,d) = \sum_{W} P(x,y,d) \qquad (1)$$

where P(x,y,d) = 1, if $abs[B_R(x,y)-B_L(x+d,y)] \leq Th$
= 0, otherwise;

abs(·) denotes the absolute value; $B_R(x,y)$ and $B_L(x+d,y)$ denote the intensity at R(x, y) and L(x+d, y), respectively; W denotes a matching window of size (Wx * Wy), a group of pixels centered at either R(x, y) in the reference image or L(x+d, y) in the search image; and Th is a predetermined threshold value.

P(x, y, d) is thus set equal to one if intensity values at corresponding pixels, i.e., R(x, y) and L(x+d, y), in the two images are similar, and zero otherwise. To determine the disparity for a reference pixel R(x, y), MPC(x, y, d) is computed for all values of d in a search range (d=0 to Sr) and the disparity is defined to be the value of d that yields the greatest value of MPC(x, y, d).

Figure 2 illustrates a comparison of SAD and MPC similarity measures. A comparison of the intensity values of

pixels in the reference image with the intensity values of pixels in the search image shows that the disparity of the three upper pixels in the reference image, which have intensity values of 10, 200, and 10, is zero and the disparity of the six lower pixels in the reference image, which have intensity values of 150, 80, 60, 70, 200 and 250, is one.

To determine the disparity of the pixel with an intensity value of 80 (the "reference pixel"), a similarity measure (either SAD or MPC) between a window in the reference image (the "reference window") and each window in the search image ("search window") is computed and the search window most similar to the reference window is selected. The displacement between the reference window and the selected search window is the disparity between the two images for the reference pixel. For sake of simplicity, only two search windows are shown in Figure 2.

In the SAD method, SAD(3,2,0) and SAD(3,2,1) are given by:

$$\begin{aligned}\mathrm{SAD}(3,2,0) = {} & \mathrm{abs}(10-10)+\mathrm{abs}(200-200)+\mathrm{abs}(10-10)\\ & +\mathrm{abs}(140-150)+\mathrm{abs}(150-80)+\mathrm{abs}(80-60)\\ & +\mathrm{abs}(80-70)+\mathrm{abs}(70-200)+\mathrm{abs}(200-250)\\ = {} & 290 \text{ and}\\ \mathrm{SAD}(3,2,1) = {} & \mathrm{abs}(200-10)+\mathrm{abs}(10-200)+\mathrm{abs}(250-10)\\ & +\mathrm{abs}(150-150)+\mathrm{abs}(80-80)+\mathrm{abs}(60-60)\\ & +\mathrm{abs}(70-70)+\mathrm{abs}(200-200)+\mathrm{abs}(250-250)\\ = {} & 620.\end{aligned}$$

In SAD(3,2,0) and SAD(3,2,1), 3 and 2 are the x and y coordinates, respectively, of the reference pixel and 0 or 1 is the disparity between reference and search windows for which the SAD is computed. The disparity for the reference pixel in the SAD method is the displacement that yields the smallest SAD value (*i.e.*, 0).

In the MPC method, MPC(3,2,0) and MPC(3,2,1) are given by:

$$\mathrm{MPC}(3,2,0) = 1+1+1+0+0+0+0+0+0=3$$

$$\mathrm{MPC}(3,2,1) = 0+0+0+1+1+1+1+1+1=6$$

The disparity for the reference pixel in the MPC method is the displacement that yields the largest MPC value (*i.e.*, 1).

In this example, the SAD measure yields a misleading disparity value, because the upper three pixels in the reference window, which exhibit a large variance in their intensity values, have a greater effect on the similarity measure than do the lower six pixels, which exhibit a small variance.

Figures 3A and 3B illustrate redundant operations which are inherent in the computation of the MPC measure. Despite the epipolar constraint, the amount of computation required to determine MPC values for all pixels in the reference image is proportional to (Ix * Iy) * (Wx * Wy) * Sr, where (Ix * Iy) is the size of an image, (Wx * Wy) is the size of a window, Wx and Wy being odd numbers, and Sr is a search range. The enormous amount of computation required is due to the redundant operations which are inherent in the MPC method.

As shown in Figure 3A, after the MPC value between R(x, y) and L(x+d, y) has been determined, the computation corresponding to the overlapping area of the two horizontally displaced windows would be redundant when determining the MPC value between R(x+1, y) and L(x+1+d, y). Similarly, when determining the MPC value between R(x, y+1) and L(x+d, y+1), the computation corresponding to the overlapping area of two vertically displaced windows in Figure 3B would be redundant.

By using buffers to store the results of computation, these redundant operations can be avoided so that the amount of computation can be reduced to (Ix * Iy) * Sr, irrespective of the size of a window.

Figures 4A and 4B illustrate a method of computing MPC values from which these redundant computations have been eliminated. For sake of simplicity, only pixels in the

reference image are shown. V(x, y, d) represents a matching pixel count between two vertical segments which are a group of Wy pixels centered at R(x, y) and L(x+d, y). MPC(wx, y, d) is computed by summing V values as follows:

$$MPC(xw, y, d) = \sum_{i=-wy}^{wy} V(wx+i, y, d) \qquad (2)$$

For x larger than wx, MPC(x,y,d) can be computed from a previously computed MPC value (*i.e.*, MPC(x-1,y,d)) as follows:

$$MPC(x,y,d) = MPC(x-1,y,d) + V(x+wx,y,d) - V(x-1-wx,y,d) \qquad (3)$$

In Equations (2) and (3), wx and wy denote distances from the center to the boundary of a window in the horizontal and vertical directions, respectively:

$$wx = (Wx-1)/2 \text{ and } wy = (Wy-1)/2 \qquad (4)$$

In a similar manner, a first V value in a column, V(x,wy,d), is computed by summing P(·) for a vertical segment:

$$V(x, wy, d) = \sum_{i=-wy}^{wy} p(x, wy+i, d) \qquad (5)$$

where P(x, y, d) has the value one if values of R(x, y) and L(x+d,y) are similar and has the value zero otherwise as defined in Equation. (1). For values of y greater than wy, V(x,y,d) can be computed by using a previously computed V value, V(x,y-1,d):

$$V(x,y,d) = V(x,y-1,d) + P(x,y+wy,d) - P(x,y-1-wy,d) \quad (6)$$

At the beginning of stereo disparity estimation for a reference image and a search image, V(x,wy,d), which represents the similarity between vertical segments centered at R(x, wy) and L(x+d, wy), is computed for all values of x and d (*i.e.*, from x=0 to x=Ix-1 and from d=0 to d=Sr) according to Equation. (5). In other words, as many as (Sr+1) V values, V(x,wy,0), V(x,wy,1), ... , V(x,wy,Sr), are computed for each x. The computed V values are stored in a V buffer which can store Ix*(Sr+1) V values.

In Equation (2), MPC(wx,y,d) represents the similarity between a window centered at R(wx,y) in the reference image and a window centered at L(wx+d,y) in the search image. A buffer for storing a MPC value is initialized with a sum of V(wx+i,y,d) values for I=-wx to wx. The initialization of the MPC buffer is done for a (wx)th pixel in each row.

For values of x greater than wx, MPC(x,y,d) is computed by using MPC(x-1,y,d), the MPC for the previous pixel in the same row, which is stored in the MPC buffer, as shown in Equation (3) and Figure 4A. Specifically, V(x+wx,y,d), a V value for a vertical segment newly added to the window, is added to the previously computed MPC value and V(x-wx-1,y,d), a V value for a vertical segment excluded from the window, is subtracted from the previously computed MPC value.

Similarly, for values of y greater than wy, V(x,y,d) can be computed without redundancies in the vertical direction. P(x,y+wy,d) indicating matching between pixels added to the vertical segment is added to the previously computed V value, V(x,y-1,d), stored in the V buffer, and P(x,y-1-wy,d) indicating matching between pixels excluded from the vertical segment is subtracted from V(x,y-1,d).

In summary, after initializing the V buffers with the V values for vertical segments centered at each pixel in the (wy)th row and initializing the MPC buffer with the MPC value for a (wx)th pixel in a row, other MPC values may be determined without redundant operations, as indicated by Equations (3) and (6). In doing this, search range for each pixel should be identical. For a pixel in the reference image R(x,y), if a best matching pixel among all the pixels of the search image in the search range is $L(x+d_{max}, y)$, $d_{max}$ is the stereo disparity for R(x,y).

Figure 5 illustrates the MPC matching algorithm without redundancies for implementing the above equations in an efficient manner. Inputs to this algorithm are: I) the intensity values of pixels R(x,y) and L(x,y) in the reference and search images, respectively, where x ranges from 0 to Ix-1 and y ranges from 0 to Iy-1; ii) Wx and Wy representing the size of a matching window, Wx, Wy being odd integers; and iii) the search range Sr. An output from this algorithm is a disparity map containing a disparity for each pixel, DM(x,y), where x ranges from wx to Ix-wx and y ranges from wy to Iy-wy.

In Step S20, y is initialized to wy. Then, in Step S30, initial V values, V(x, wy, d) for x=0 to Ix-1, d=0 to Sr, are computed and the results are stored in the V buffers. Since the x coordinate of a pixel cannot exceed Ix-1 and R(x+d, y) is used in the computation, x ranges from 0 to Ix-1-d, instead of Ix-1.

In Step S100, the MPC values are either initialized or updated, depending on the value of x, and the V values are updated. This step is executed for each value of x, y and d (x=wx to Ix+wx, y=wy to Iy-wy-1, d=0 to Sr). If x=wx, Equation (3) is executed to generate the first MPC value in the row. If the value of x is less than Ix-d-wx and greater than wx, Equations (3) and(6) are executed. If x is greater than or

equal to Ix-d-wx, only the V values are updated. After y is incremented, the V values updated in S100 are used to compute the MPC values for the next row.

Steps S40, S50, S60, S70, S80, S90, and S95 repeat Step S100 for the given ranges of x, y and d.

Steps S130 and S140 determine the value of d that yields the greatest MPC value as the disparity for the reference pixel. After all the steps have been completed, a depth map DM(x,y) (for x= wx to Ix-wx, y=wy to Iy-wy) is obtained.

Figure 6 illustrates an apparatus for determining the disparity values in accordance with the present invention. The apparatus includes a P-buffer 100, an MPC processor 200 and a V-buffer 300 in which Wx and Wy are set to seven, so that the size of a window is 7x7, and Sr is set to 63. Inputs to the apparatus are pixel values of the reference and search images and Th for determining whether two pixels are similar. Synchronization signals, HSync and VSync are also input to the apparatus. Outputs from this apparatus are the maximum MPC(x,y,d) value (MaxV) for pixel R(x,y) in the reference image and disparity DM(x,y) which yields the maximum MPC value.

The MPC processor 200 includes a P-unit 210, MPC-units 220, a Max_MPC selector 230 and a control unit 240. The MPC processor 200 includes (Sr+1) MPC units 220, so that for each reference pixel R(x, y), (Sr+1) MPC values for a search range are computed in parallel. Pixel values R(x,y) and L(x+d,y) are fed to the P-unit 210, where P(x,y,d) is determined according to Equation (1). In the P-unit 210, (Sr+1) P(x,y,d)-values for a given (x,y) (d=0 to Sr) are determined in parallel. The P-values are provided to the P-buffer 100 and stored therein.

The P values stored in the P-buffer 100 are coupled to the (Sr+1) MPC-units 220, where MPC(x,y,d) and V(x,y,d) are computed. A vector Pv(d), a set of P values for a same d

value, are input to the MPC-units 220 from the P-buffer 100 V(x,y,d) computed at the MPC units 220 (Vo in the figure) is input to the V-buffer 300 and stored therein. Each of the MPC-units 220 computes the MPC value for each d by using a V value computed therein and V values retrieved from the V-buffer 300. To do this, Va and Vi, V values for vertical segments added to and excluded from a matching window, respectively, are provided from the V-buffer 300 to each of the MPC-units 220.

Max_MPC selector 230 receives (Sr+1) MPC values for a pixel R(x,y) from the MPC-units 220 and determines a largest one (MaxV) to provide DM(x, y).

Figure 7A illustrates the internal structure of the P-buffer 100, which includes (Sr+1) parallel (Ix*Wy) bit shift registers. The P-buffer stores the P(x,y,d) values (identified as Pi in the figure) provided from the P-unit 210 in the MPC processor 200 and timely provides them to the (Sr+1) MPC-units 220. Each of the blocks identified as P_R(x,y) stores 64 (*i.e.*, (Sr+1)) 1-bit P(x,y,d)-values and the P(x,y,d)-values are shifted in synchro- nization with a system clock, as indicated by the arrows. In Figure 7A, each row of blocks corresponds to a row of an image and each column of blocks corresponds to a vertical segment in a window (*i.e.*, Wy consecutive pixels in a column). Thus, P(x,0,d) to P(x,Wy-1,d) P-values for pixels included in the same vertical segment are provided from the left part of the P-buffer 100, where each of P(x,0,d) to P(x,Wy-1,d) represents 64 P-values (either 0 or 1) for d=0 to 63. These values are realigned according to the d values into Sr+1 Pv(d) so that Wy (in this example, 7) P values for a same d constitute a vector Pv(d). Since the P-buffer 100 is constructed with shift registers, desired results are provided when the registers are fully occupied by P values, that is, Ix * Wy clocks after a data is first fed to the P-buffer. Then, Pv(d)s are provided from the P-buffer 100 consecutively. Each Pv(d) from the P-buffer 100 is fed back to each MPC-unit in the MPC-processor 200 to be used in

computing V.

Figure 7B shows the internal structure of the V-buffer 300. The V-buffer 300 temporarily stores V(x,y,d) values which are computed at the (Sr+1) MPC-units 220. Each block identified as V_R(I) stores 64 (d=0 to 63) 3-bit V(x,y,d) values. The data in each block is shifted to a next block in synchronization with a clock signal. Data Stored in V_R(Wx) and V_R(0) are provided as outputs from the V-buffer 300, which correspond to V values for vertical segments added to and subtracted from a matching window, respectively. In other words, each of Vw(0) to Vw(63) represents a V value for a vertical segment added to a window for d=0 to 63 in the computation of MPC. Similarly, each of Vo(0) to Vo(63) represents a V value for a vertical segment excluded from a window for d=0 to 63. The V-buffer 300 also has initial delay of (Ix-Wx) clock cycles. Outputs from the V-buffer 300 are provided to the MPC-unit 220 to be used in computing MPC values according to Equation (3).

Figure 8A shows an internal structure of the P-unit 210 included in the MPC-processor 200. Inputs to the P-unit 210 are R, S and Th where R and S denote pixel values of reference and search images, and Th denotes the threshold for determining P(x,y,d). Assuming that a pixel value ranges from 0 to 255($2^8$-1), 8 bits are assigned to each R and S input. The P-unit 210 receives (Sr+1) pixel values in a search image for each pixel in a reference image and determines P(x,y,d) for them. A processing unit denoted as D_P(d), d=0 to Sr, determines P(x,y,d) for the reference pixel ( *i.e.*, the pixel in the reference image) and a pixel in the search image displaced from the reference pixel by d.

Figure 8B is a circuit diagram of the D_P unit 211. Full adders (FA) 211-1 in the left part subtract S from R. Carry generators (CG) 211-3 in the right part provide a carry, denoted as D, depending upon the sign of (Th-abs(R-S)). If Th

is greater than the absolute value of (R-S), D is 1. If (R-S), the input to the XOR gates 211-2, is a positive number, the 2's complement of the inputs (i.e., -(R-S)) is provided by the gates 211-2. If (R-S) is a negative number, (R-S) is provided by the XOR gates, so that the absolute value of (R-S) can be subtracted from Th. Since there are (Sr+1) D_P(d) units 211 in the P_units 210, (Sr+1) P(x,y,d) values may be calculated in parallel. In the P-unit 210 shown in Figure 8A, a pixel value in a reference image is used only once, while a pixel value in the search image is used (Sr+1) times as it is shifted through D_R(d). D_R(d) denotes the registers that store pixel values of the search image. A pixel value in each D_R(d) is shifted left on each clock. As the P-unit 210 includes the shift registers, it provides an output continuously after an initial delay of (Sr+1) clock cycles.

Figure 9 illustrates the internal structure of the MPC-unit 220 in the MPC processor 200. The MPC-unit 220 is divided by its function into a V_MP counter 221 and a V_MP update unit 222 for calculating V(x,y,d) according to Eqs. (5) and (6), respectively, and a W_MP count and update unit 223 for calculating MPC(x,y,d) according to Eqs. (2) and (3). The V_MP counter 211 is used to provide V(x,y,d) by summing P values inputted in an initial stage of the disparity map computation. After the initial stage, V (denoted as Vi in the figure) is provided to the V_MP update unit 222 from the V-buffer 300. Then, V_MP update unit 222 calculates V(x,y,d) without redundant operation.

Figure 10 depicts a logic diagram of the MPC-unit 220. The V_MP counter 221 receives Wy P values in an initial stage, adds them at four full adders (FAs) included in the V_MP counter 221, thereby providing a 3-bit binary number V(x,y,d). This 3-bit value (Vo(2), Vo(1), Vo(0)) is provided to the V-buffer 300 through a MUX A 225. C2 control input makes the MUX A 225 select an output from the V_MP counter 221 until an output from the V_MP update unit 222 becomes valid. V(x,y,d)

values input to the V-buffer 300 are provided to the Va input port of the MPC-unit 220 after (Ix-Wx) clock cycles and to the Vi input port after Ix clock cycles. V_MP update unit 222 begins to calculate V(x,y,d) without redundancy according to Equation (6) by adding one to Vi or subtracting one from Vi at the full adders 222-3, depending on the values of Pv(0) and Pv(6). Specifically, if Pv(0) is equal to Pv(6), 0 (000 in binary) is added to Vi; Pv(0) is 1 and Pv(6) is 0, -1 (111 in binary) is added to Vi; and Pv(0) is 0 and Pv(6) is 1, 1 (001 in binary) is added to Vi. Then, the C2 control input enables the MUX A 225 to select the outputs from the V_MP update unit 222.

Vi and Va, provided from the V-buffer 300 to the MPC-unit 220, are used to calculate MPC values according to Equations (2) and (3). Full adders 223-1 on the left part of the W_MP count and update unit 223 calculate Va-Vi. The result is added to a previous MPC value in the adders 223-2 on the right part of the W_MP count and update unit 223 in order to provide an updated MPC value. MUX B 224 selects 0's and provides them to the W_MP count and update unit 223 until Vi from the V-buffer 300 becomes valid. As a result, until Vi becomes valid, only Va values are summed in the unit 223 to provide MPC(wx, y, d) according to Equation (2). After Vi from the V-buffer becomes valid, MPC is calculated according to Equation (3).

Figure 11 shows the internal structure of the Max_MPC selector 230 included in the MPC-processor 200 in Figure 6. The Max_MPC selector 230 compares MPC values provided from the (Sr+1) MPC-units 220, selects a maximum value MaxV and provides a displacement DM(x,y) corresponding to the maximum value. Basic units for constructing the Max_MPC selector 230 are C&A(n) cells 231 each of which compares its inputs and provides the larger one and its location information.

Figure 12 is a logic diagram of the C&A(n) cell. In the C&A cell 231, carry generators 231-1 provides 0 if Ib is

smaller than Ia and 1 otherwise so that MUXes 231-3 select and provide the larger value. MUXes 231-2 produce the location information (S(n) , ... , S(0)) corresponding to the larger value in response to the location information from a previous stage, i.e., C&A(n-1), and the carry value. The number of MUXes in the C&A cell varies depending on n, that is, the number of MUXes 231-2 is n. The MUXes 231-2 select one between Sa and Sb, the location information of a previous stage. In Fig. 11, going further to the right, number of bits inputted as Sa and Sb to C&A cell increases. The output from the C&A cell of the last stage is a maximum MPC value for a given pixel R(x,y) and its disparity.

While the present invention has been described in terms of particular embodiments, it will be apparent to those of ordinary skill in the art that various changes and modifications may be made without departing from the spirit and scope of the invention defined in the following claims.

Claims:

1. A method of determining a stereo disparity between a reference image and a search image for a reference pixel in the reference image, said method comprising the steps of:

(a) calculating a similarity measure between a reference window including a set of pixels centering on the reference pixel and each of a group of search windows in the search image which is of a same shape with the reference window and displaced from the reference window within a predetermined search range, wherein a matching pixel count, which is the number of pixels in the reference window which are similar in intensity to corresponding pixels in a search window, is used as the similarity measure between the reference window and said search window; and

(b) determining a displacement between the reference window and a search window which yields a largest similarity measure as the stereo disparity for the reference pixel.

2. A method of determining a stereo disparity as defined in Claim 1, wherein R(x,y) represents the reference pixel, the reference window includes Wx*Wy pixels centering on R(x,y), Wx and Wy being predetermined numbers, each of the search windows includes Wx*Wy pixels centering on L(x+d, y) which is a pixel in the search image, d ranging from 0 to a predetermined number Sr, and

said step (a) includes:

(a1) calculating P(x,y,d) values as follows:

$$P(x,y,d) = 1, \text{ if } abs(B_R(x,y)-B_L(x+d,y)) \leq Th$$
$$= 0, \text{ otherwise},$$

where $B_R(x,y)$ and $B_L(x+d,y)$ represent intensity values of R(x, y) and L(x+d, y) and Th is a predetermined threshold; and

(a2) determining MPC(x,y,d) values for d=0 to Sr as follows:

$$MPC(x,y,d) = \sum_{w} P(x,y,d)$$

wherein w represents the reference window and the search window centering on L(x+d,y); and

said step (b) includes selecting a d value which yields a largest MPC(x,y,d) value as the stereo disparity for R(x,y).

3. An apparatus for determining a stereo disparity between a reference image and a search image for a reference pixel in the reference image, said apparatus comprising:

(a) first means for calculating a similarity measure between a reference window including a set of pixels centering on the reference pixel and each of a group of search windows in the search image which is of a same shape with the reference window and displaced from the reference window within a predetermined search range, wherein a matching pixel count, which is the number of pixels in the reference window which are similar in intensity to corresponding pixels in a search window, is used as the similarity measure between the reference window and said search window; and

(b) second means for determining a displacement between the reference window and a search window which yields a largest similarity measure as the stereo disparity for the reference pixel,

wherein R(x,y) represents the reference pixel, the reference window includes Wx*Wy pixels centering on R(x,y), Wx and Wy being predetermined numbers, each of the search windows includes Wx*Wy pixels centering on L(x+d, y) which is a pixel in the search image, d ranging from 0 to a predetermined number Sr, and

said first means includes:

(a1) a P-unit for calculating P(x,y,d) values as follows:

$P(x,y,d) = 1,\ \text{if}\ abs(B_R(x,y) - B_L(x+d,y)) \leq Th$

= 0, otherwise,

where $B_R(x,y)$ and $B_L(x+d,y)$ represent intensity values of R(x,y), and L(x+d,y) and Th is a predetermined threshold value;

(a2) a P-buffer for storing P(x,y,d) values from said P-unit;

(a3) third means for determining MPC(x,y,d) values for d=0 to Sr as follows:

$$MPC(x,y,d) = \sum_{w} P(x,y,d)$$

where w represents the reference window and the search window centering on L(x+d,y); and

said second means includes means for selecting a d value which yields a largest MPC(x,y,d) value as the stereo disparity for R(x,y).

4. An apparatus as defined in Claim 3, wherein said third means includes (Sr+1) MPC-units, each of which determines MPC(x,y,d) for each d value.

5. An apparatus as defined in Claim 4, wherein each of said MPC-units includes:

means for determining V(x,y,d) values which is represented as follows:

$$V(x,y,d) = \sum_{i=-wy}^{wy} P(x,y+i,d)$$

where wy is (Wy-1)/2;

means for generating a MPC(x,y,d) value by using V(x,y,d) values as follows:

$$MPC(x,y,d) = \sum_{i=-wx}^{wx} V(x+i,y,d)\ ,\ if\ x=wx\ and$$

MPC(x,y,d)= MPC(x-1,y,d)+V(x+wx,y,d)-V(x-1-wx,y,d), if x>wx,
where wx is (Wx-1)/2.

6. An apparatus as defined in Claim 5, further comprising a V-buffer for storing the V(x,y,d) values from said V determining means and providing the stored V(x,y,d) values to said MPC generating means.

7. An apparatus as defined in Claim 6,
wherein said V determining means includes:
a V_MP counter for determining V(x,y,d) values for by summing P values as follows:

$$V(x,y,d) = \sum_{i=-wy}^{wy} P(x,y+i,d)$$

a V_MP update unit for determining V(x,y,d) values by using V(x,y-1, d) and P values as follows:
V(x,y,d)=V(x,y-1,d)+P(x,y+wy,d)-P(x,y-1-wy,d); and
a multiplexor for selectively providing the V(x,y,d) value from the V_MP counter if y=wy and the V(x,y,d) value from the V_MP update unit if y≥wy; and
said MPC generating means includes:
a W_MP count and update unit for generating a MPC(x,y,d) value by using V(x,y,d) values; and
a multiplexor for selectively providing V(x,y,d) values from the V-buffer or 0 to the W_MP count and update unit as the V(x-1-wx,y,d) value.

8. An apparatus as defined in Claim 7, wherein

said V_MP counter includes a plurality of full adders;

said V_MP update unit includes:

logic gates for providing P(x,y+wy,d)-P(x,y-1-wy,d); and

full adders for adding the output from the logic gates to V(x,y-1,d), thereby providing V(x,y,d); and

said W_MP count and update unit includes:

means for deciding V(x+wx,y,d)-V(x-1-wx,y,d); and

means for adding the output from said deciding means to MPC(x-1,y,d).

9. An apparatus as defined in Claim 3, wherein said P-unit includes:

(Sr+1) D_R units each of which stores L(x+d,y) values for each d; and

(Sr+1) D_P units which provides (Sr+1) P(x,y,d) values for d=0 to Sr simultaneously in response to R(x,y) and (Sr+1) L(x+d, y) values from the D_R units.

10. An apparatus as defined in Claim 9, wherein the D_P unit includes:

means for calculating ($B_L$(x+d,y)-$B_R$(x,y)) which includes a plurality of full adders;

means for calculating an absolute value of ($B_L$(x+d,y)-$B_R$(x,y)) which includes a plurality of exclusive OR gates; and

means for subtracting the absolute value from Th and providing 0 or 1 depending on the result of the subtraction, which includes a plurality of carry generators.

11. An apparatus as defined in Claim 3, further comprising means for selecting a largest one among the MPC(x,y,d) values for R(x,y) and providing a d value yielding the largest MPC value as the disparity for R(x,y).

12. An apparatus as defined in Claim 3, where said P-buffer includes means for storing Ix *Wy*(Sr+1) P values, wherein Ix is the number of pixels in a row in the reference and the

search image.

13. An apparatus as defined in Claim 6, where said V-buffer includes means for storing Ix*(Sr+1) V values, wherein Ix is the number of pixels in a row in the reference and the search image.

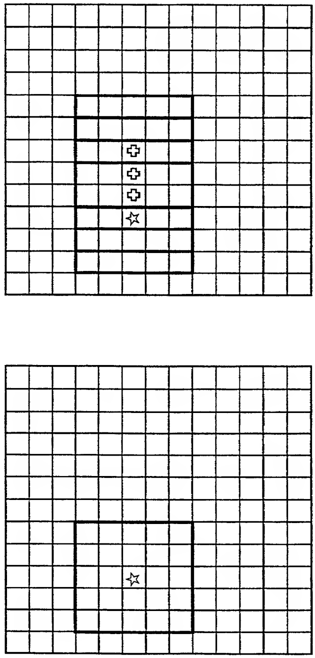



Fig. 1

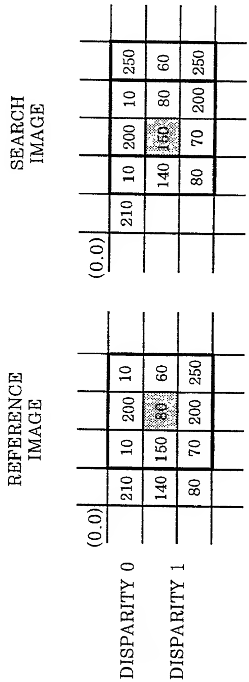

REFERENCE IMAGE
SEARCH IMAGE
(0.0)
210 10 200 10
140 150 80 60
80 70 200 250
(0.0)
210 10 200 10 250
140 150 80 60
80 70 200 250
DISPARITY 0
DISPARITY 1

Fig. 2

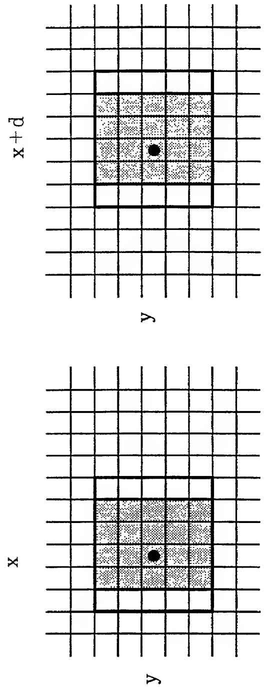



Fig. 3a

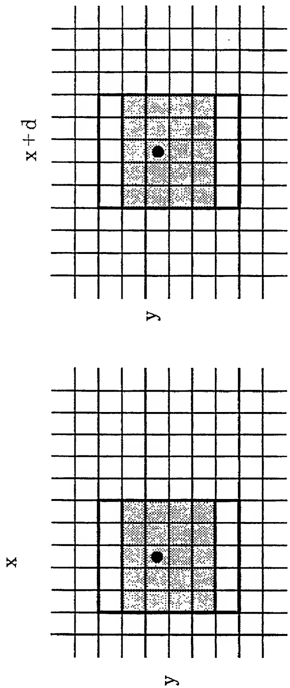
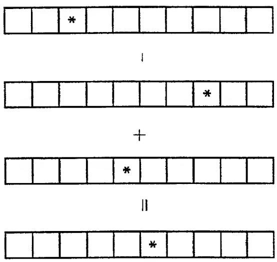


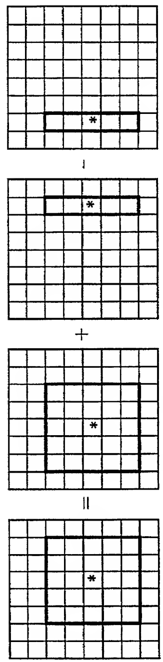

Fig. 3b

Fig. 4a



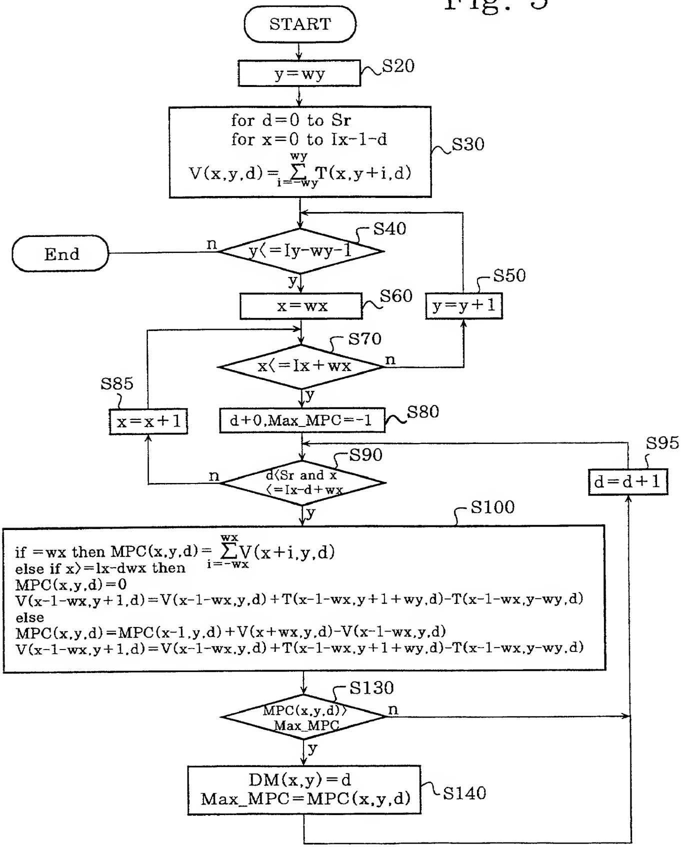
$$V(x,y,d)=V(x,y-1,d)+T(x,y+wy,d)-T(x,y-1-wy,d)$$

Fig. 4b



$$MPC(x,y,d)=MPC(x-1,y,d)+V(x+wx,y,d)-V(x-wx-1,y,d)$$

Fig. 5


START
y=wy
S20
for d=0 to Sr
for x=0 to Ix-1-d
V(x,y,d) = Σ_{i=-wy}^{wy} T(x,y+i,d)
S30
S40
y<=Iy-wy-1
n
End
y
x=wx
S60
S50
y=y+1
S70
x<=Ix+wx
n
y
S85
x=x+1
d+0,Max_MPC=-1
S80
S90
d<Sr and x <=Ix-d+wx
n
y
S95
d=d+1
S100
if =wx then MPC(x,y,d)= Σ_{i=-wx}^{wx} V(x+i,y,d)
else if x>=lx-dwx then
MPC(x,y,d)=0
V(x-1-wx,y+1,d)=V(x-1-wx,y,d)+T(x-1-wx,y+1+wy,d)-T(x-1-wx,y-wy,d)
else
MPC(x,y,d)=MPC(x-1,y,d)+V(x+wx,y,d)-V(x-1-wx,y,d)
V(x-1-wx,y+1,d)=V(x-1-wx,y,d)+T(x-1-wx,y+1+wy,d)-T(x-1-wx,y-wy,d)
S130
MPC(x,y,d)> Max_MPC
n
y
DM(x,y)=d
Max_MPC=MPC(x,y,d)
S140

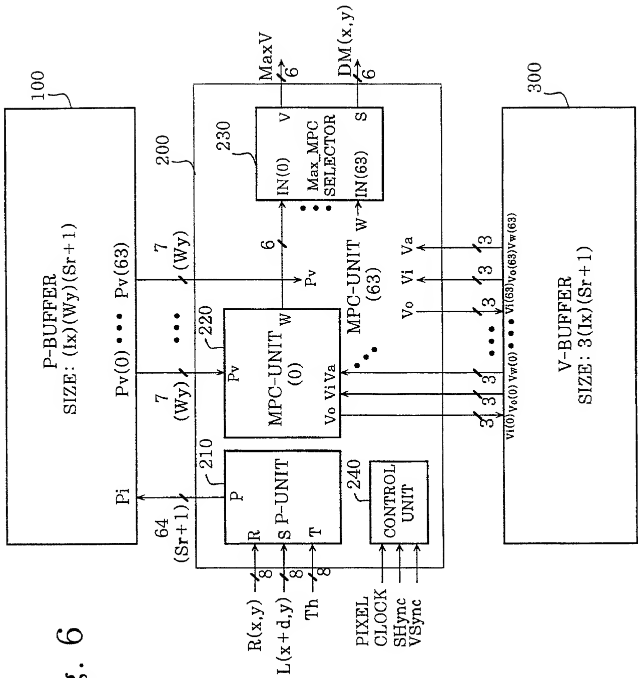

100
P-BUFFER
SIZE : (Ix)(Wy)(Sr+1)
Pi
Pv(0)
Pv(63)
200
210
P-UNIT
P
R
S
T
220
MPC-UNIT (0)
Pv
W
Vo Vi Va
MPC-UNIT (63)
230
Max_MPC SELECTOR
IN(0)
IN(63)
V
S
MaxV
DM(x,y)
240
CONTROL UNIT
64 (Sr+1)
7 (Wy)
6
8
3
R(x,y)
L(x+d,y)
Th
PIXEL CLOCK
SHync
VSync
300
V-BUFFER
SIZE : 3(Ix)(Sr+1)
Vi(0) Vo(0) Vw(0)
Vi(63) Vo(63) Vw(63)

Fig. 6

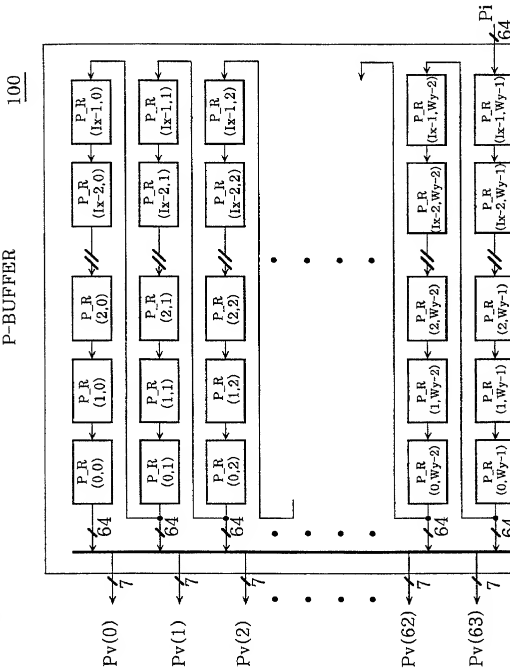

100
P-BUFFER
Pi
64
P_R (Ix-1,0)
P_R (Ix-2,0)
P_R (2,0)
P_R (1,0)
P_R (0,0)
P_R (Ix-1,1)
P_R (Ix-2,1)
P_R (2,1)
P_R (1,1)
P_R (0,1)
P_R (Ix-1,2)
P_R (Ix-2,2)
P_R (2,2)
P_R (1,2)
P_R (0,2)
P_R (Ix-1,Wy-2)
P_R (Ix-2,Wy-2)
P_R (2,Wy-2)
P_R (1,Wy-2)
P_R (0,Wy-2)
P_R (Ix-1,Wy-1)
P_R (Ix-2,Wy-1)
P_R (2,Wy-1)
P_R (1,Wy-1)
P_R (0,Wy-1)
64
7
Pv(0)
Pv(1)
Pv(2)
Pv(62)
Pv(63)

Fig. 7a

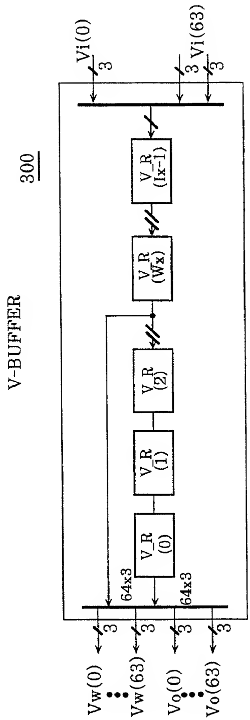

V-BUFFER
300
Vi(0)
Vi(63)
3
V_R (Ix-1)
V_R (Wx)
V_R (2)
V_R (1)
V_R (0)
64x3
64x3
Vw(0)
Vw(63)
Vo(0)
Vo(63)

Fig. 7b

09/623516



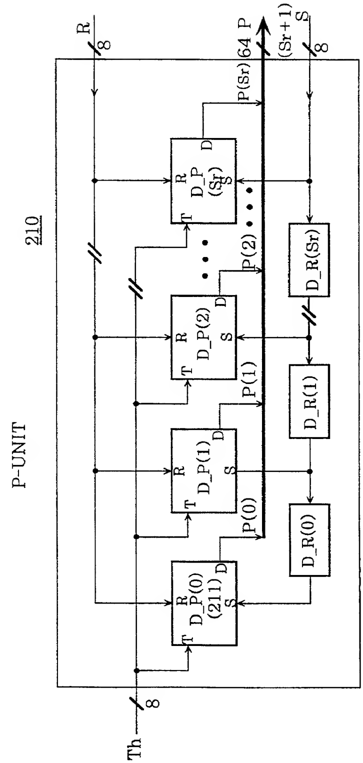



Fig. 8a

# Fig. 8b

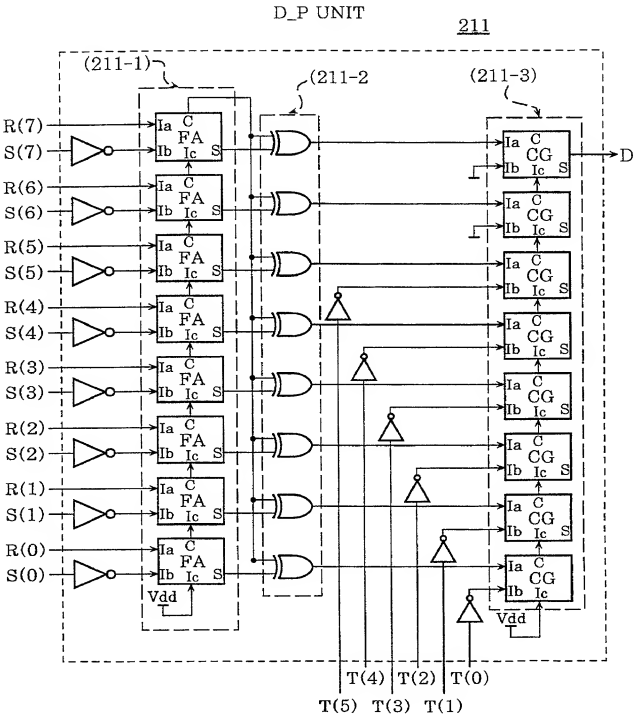

D_P UNIT
211
(211-1)
(211-2
(211-3)
R(7)
S(7)
R(6)
S(6)
R(5)
S(5)
R(4)
S(4)
R(3)
S(3)
R(2)
S(2)
R(1)
S(1)
R(0)
S(0)
Ia C FA Ib Ic S
Ia C CG Ib Ic S
Vdd
D
T(4)
T(2)
T(0)
T(5)
T(3)
T(1)

Fig. 9

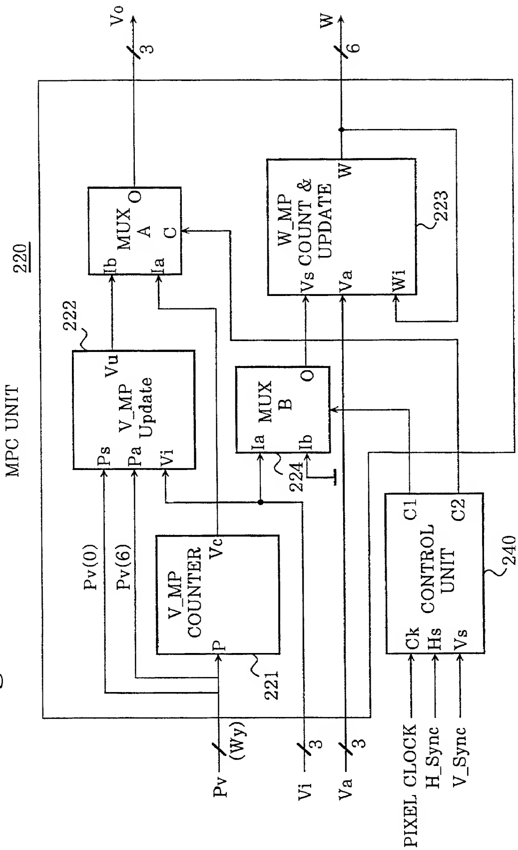

MPC UNIT
220
V_MP COUNTER
P
Vc
221
V_MP Update
Ps
Pa
Vi
Vu
222
MUX A
Ib
Ia
C
O
MUX B
Ia
Ib
O
224
W_MP COUNT & UPDATE
Vs
Va
Wi
W
223
CONTROL UNIT
Ck
Hs
Vs
C1
C2
240
Pv(0)
Pv(6)
Pv
(Wy)
Vi
3
Va
3
PIXEL CLOCK
H_Sync
V_Sync
Vo
3
W
6

Fig. 10

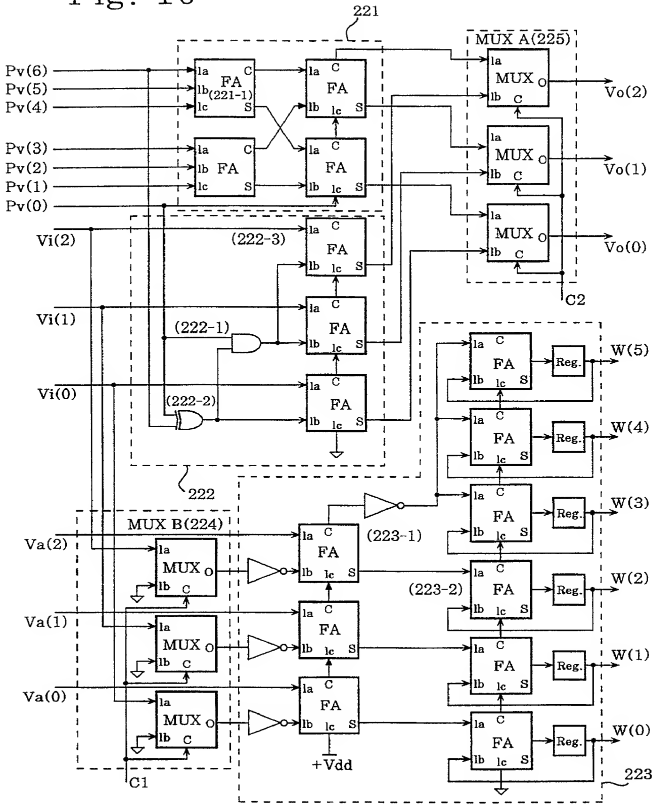
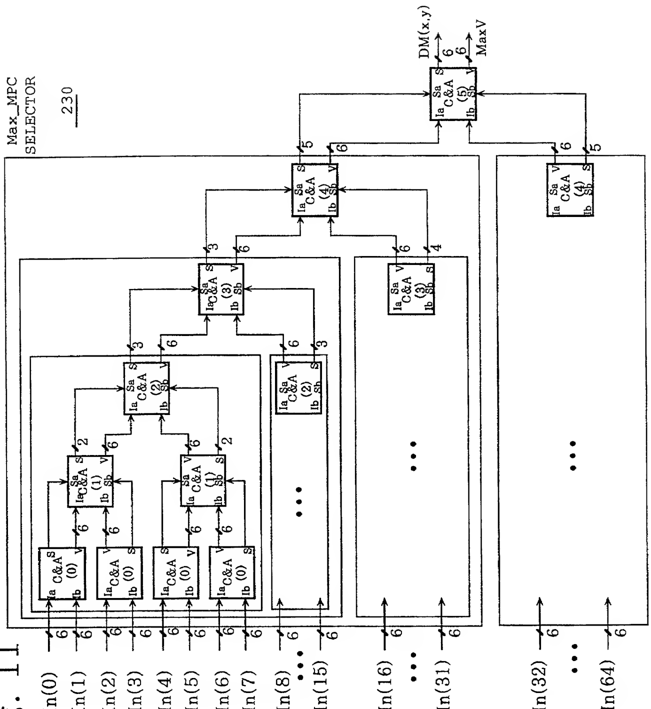
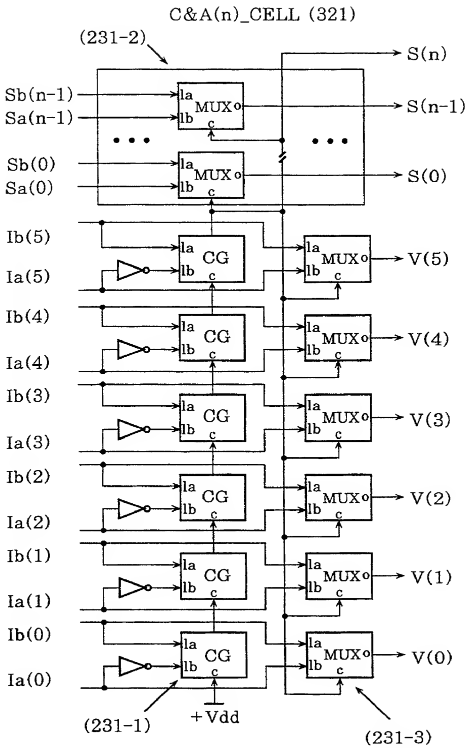

221
MUX A(225)
Pv(6)
Pv(5)
Pv(4)
Pv(3)
Pv(2)
Pv(1)
Pv(0)
FA
(221-1)
FA
MUX
Vo(2)
Vo(1)
Vo(0)
C2
Vi(2)
(222-3)
Vi(1)
(222-1)
Vi(0)
(222-2)
222
W(5)
W(4)
W(3)
W(2)
W(1)
W(0)
Reg.
MUX B(224)
Va(2)
Va(1)
Va(0)
(223-1)
(223-2)
+Vdd
C1
223

Fig. 11


Max_MPC
SELECTOR
230
DM(x,y)
MaxV
C&A (0)
C&A (1)
C&A (2)
C&A (3)
C&A (4)
C&A (5)
Ia
Ib
Sa
Sb
S
V
In(0)
In(1)
In(2)
In(3)
In(4)
In(5)
In(6)
In(7)
In(8)
In(15)
In(16)
In(31)
In(32)
In(64)

# Fig. 12


C&A(n)_CELL (321)
(231-2)
Sb(n-1)
Sa(n-1)
la
lb
MUX
o
c
S(n)
S(n-1)
Sb(0)
Sa(0)
S(0)
Ib(5)
Ia(5)
CG
V(5)
Ib(4)
Ia(4)
V(4)
Ib(3)
Ia(3)
V(3)
Ib(2)
Ia(2)
V(2)
Ib(1)
Ia(1)
V(1)
Ib(0)
Ia(0)
V(0)
(231-1)
+Vdd
(231-3)

ATTORNEY/DOCKET NO:

# DECLARATION FOR PATENT APPLICATION AND APPOINTMENT OF ATTORNEY

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name; I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention (Design, if applicable) entitled:

METHOD AND APPARATUS FOR MEASURING SIMILARITY USING MATCHING PIXEL COUNT

the specification of which (check one):

☐ is attached hereto, or ☒ was filed on: as U.S. Application Number or PCT International Application Number: PCT/KR99/00174 and (if applicable) was amended on:

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose information which is material to patentability as defined in *Title 37, Code of Federal Regulations, §1.56*. I hereby claim foreign priority benefits under *Title 35, United States Code §119* of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

| PRIOR FOREIGN APPLICATION(S) | | | PRIORITY CLAIMED | |
|---|---|---|---|---|
| **Number** | **Country** | **Day/Month/Year Filed** | **Yes** | **No** |
| 13970 | KOREA | 13/04/1998 | X | |
| | | | | |

☐ Additional Priority Application(s) Listed on Following Page(s)

| I HEREBY CLAIM THE BENEFIT UNDER TITLE 35 U.S. CODE §119(E) OF ANY U.S. PROVISIONAL APPLICATIONS LISTED BELOW. | |
|---|---|
| **Application Number** | **Day/Month/Year Filed** |
| | |
| | |

☐ Additional Provisional Application(s) Listed on Following Page(s)

I hereby claim the benefit under *Title 35, United States Code, §120* of any United States application(s) or PCT international application(s) designating The United States of America listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of *Title 35, United States Code, §112*, I acknowledge the duty to disclose information which is material to patentability as defined in *Title 37, Code of Federal Regulations, §1.56* which became available between the filing date of the prior application(s) and the national or PCT international filing date of this application:

| Application Number | Filing Date | Status - Patented, Pending or Abandoned |
|---|---|---|
| | | |
| | | |

☐ Additional US/PCT Priority Application(s) listed on Following Page(s)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under *section 1001 of title 18 of the United States Code* and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: I (We) hereby appoint as my (our) attorneys, with full powers of substitution and revocation, to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: J. Ernest Kenney, Reg. No. 19,179; Eugene Mar, Reg. No. 25,893; Richard E. Fichter, Reg. No. 26,382; Thomas J. Moore, Reg. No. 28,974; Joseph DeBenedictis, Reg. No. 28,502; Benjamin E. Urcia, Reg. No. 33,805; and

I(we) authorize my(our) attorneys to accept and follow instructions from ______________________ regarding any matter related to the preparation, examination, grant and maintenance of this application, any continuation, continuation-in-part or divisional based thereon, and any patent resulting therefrom, until I(we) or my(our) assigns withdraw this authorization in writing.

Send correspondence to: **BACON & THOMAS, PLLC**
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| DATE SEPTEMBER 30, 2000 | SIGNATURE Kim Hyoung Gon |

☐ *See following page(s) for additional joint inventors.*

Attorney/Docket No:

# Continuation of Declaration for Patent Application and Appointment of Attorney

Page ___

| Prior Foreign Application(s) (35 USC §119) | | | Priority Claimed | |
|---|---|---|---|---|
| Number | Country | Day/Month/Year Filed | Yes | No |
| | | | | |
| | | | | |

| Prior Provisional Applications 35 U.S. Code §119(e) | |
|---|---|
| Application Number | Day/Month/Year Filed |
| | |
| | |

| Prior U.S. or PCT International Applications (35 U.S. Code §120) | | |
|---|---|---|
| Application Number | Filing Date | Status - Patented, Pending or Abandoned |
| | | |
| | | |

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| Date SEPTEMBER 30, 2000 | Signature 김 |

| | |
|---|---|
| Full Name of Joint Inventor | Citizenship |
| Residence Address | Post Office Address is the same as Residence Address unless otherwise shown below |
| Date | Signature |

☐ *See following pages for additional joint inventors/priority applications.*